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TECHNICAL REPORT ARLCD-TR-78054

EFFECTS OF ADHESIVE AND PROCESSING PARAMETERS ON ADHESIVE BONDING OF POLYCARBONATE

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Change item 3, page 5, in the basic publication to read as follows:

3. Whether ethanol wipe or sanding surface treatment is used appears to be immaterial as far as strength and durability of polycarbonate bonds is concerned.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Weibull distribution was found to be quite useful in studying the effects of adhesive and processing parameters on adhesive bonding of polycarbonate. Adhesive selection is very important in satisfactorily bonding this polymer. Ethanol wipe and sanding as surface pretreatments of the polycarbonate appear to be equivalent. The humidity exposure of polycarbonate before and during bonding is briefly discussed. Surface exposure times (SET) of up to 30 days appear not to affect strength of either tested or aged specimens of urethane adhesive bonds. The lower-strength epoxy

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bonds aged 30 days at 49°C (120°F) and 95% RH lose strength after the 30-day SET.

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INTRODUCTION

The effects of processing parameters on adhesive bonding of metals, specifically aluminum (ref. 1, 2), titanium (ref. 3), and ferrous metals (ref. 4), have been the subject of continuing study by Picatinny/ARRADCOM Applied Science personnel. Particular emphasis has been placed on surface exposure times (SET), since these times can be significant in an assembly line operation. Generally, SET times of 10 to 30 days do not affect bond strengths, and treated metal parts can be wrapped and stored for a number of days before assembly is completed without adverse effect. The effects of other factors, such as surface treatment, adhesive characteristics, and aging, have also been investigated.

This report documents a more recent study of the effects of these parameters on the bonding of an important new organic structural polymer, polycarbonate (Lexan). Since the experimental procedures and the data used in this study were developed during the earlier work and are available in reference 5, they are not repeated in this report.

RESULTS AND DISCUSSION

Two adhesives were used in this study: a two-component urethane, Uralane 5738, and a two-component epoxy, Epon 828/Versamid 140.

To prepare the dry specimens, half of the Lexan panels were dried for 24 hours at 60°C (140°F) before the surfaces were treated; the other half (the wet specimens) were kept for 24 hours at 49°C (120°F) and 95% relative humidity (RH).

All of the panels were wiped with ethanol and air dried. The faying surfaces of one-half of the panels were sanded by hand (sanded specimens) before bonding while the other half were bonded directly after the ethanol wipe and air drying (ethanol wipe).

SET times of 0 to 4 hours, 15 days, and 30 days were obtained by conditioning the surface-prepared specimens at 23°C (73°F) and 50% RH for these times. The aged specimens were conditioned for 30 days at 49°C (120°F) and 95% RH before testing.

Since the data tended to show the usual adhesive-bond-strength scatter, it was quite difficult to draw firm conclusions visually as to the effect of the various parameters. The earlier work (refs. 1-4) indicated

that metal-bond-strength data could readily be fitted with a Weibull distribution function, which was also applicable to the present polycarbonate data.

The Weibull distribution function (ref. 6, 7) was used in the form

$$\log \log \left[\frac{1}{1-F(X)}\right] = -\log \alpha + \beta \log (X-\gamma) \tag{1}$$

where F (X) is the distribution function, i.e., the fraction of samples failing at a strength (psi or Pa) of X or less, X corresponds to the strength values, and α, β, and γ are the parameters of the function. A plot of the left-hand side of equation (1) versus log $(X - \gamma)$ should give a straight line. γ is selected on an iterative basis by making trial plots. α and β may be evaluated from the intercept and the slope.

In the application to the present data, all data points are tabulted in order of increasing bond strength and the data are plotted, according to equation (1), with $\gamma = 0$. The correlation coefficients (table 1) indicated that taking $\gamma = 0$ and using a two-parameter Weibull distribution appears to be satisfactory.

The linear Weibull distribution plots are shown in figure 1; correlation coefficients are given in table 1. It is immediately evident from these plots that the urethane adhesive (Uralane 5738) forms stronger bonds with polycarbonate than the epoxy (Epon 828/Versamid 140). Even the aged Uralane bonds are somewhat stronger than the unaged epoxy, although aging 30 days at 49°C (120°F) and 95% RH reduces bond strength in each case. A numerical comparison can readily be obtained from figure 1 at any value of F (X). For example, taking F (X) = 0.50, we obtain the bond strength values in table 2 which enables us to compare actual bond strengths easily.

For both the Uralane tested at 23°C (73°F) and 50% RH and the aged specimens, a single line with correlation coefficient in the 0.99 region describes all of the data in each case. This would indicate that the ethanol wipe and sanding treatments are equivalent for the Uralane-bonded specimens. SET times of 0 to 4 hours, 15 days, and 30 days are also indistinguishable for these bonds.

Essentially the same results described for the urethane bonds were obtained for the epoxy bonds tested at 23°C (73°F) and 50% RH. A single Weibull line with correlation coefficient 0.994 described all of the data. Ethanol wipe and sanding of polycarbonate surfaces could not be distinguished. SET times of 0-4 hours, 15 days and 30 days gave essentially the same strengths.

The results for the aged epoxy are more complicated. Figure 1 and table 2 show that the bond strengths are quite low. The data scatter is also very troublesome, a fact that might be anticipated from the low bond strengths. The plot of all of the data is not satisfactory. Examination of the data indicated that values for the aged epoxy with dry, ethanol-wiped polycarbonate were much lower than for the other aged epoxy conditions. The plots in figure 1 thus give two distributions for aged epoxy and show that the data are much better represented by two distributions. The origin of the extraordinarily low strengths for the aged epoxy-dried, ethanol-wiped panels is obscure.

The distribution in figure 1 with only nine points was plotted with a table of plotting positions from which appropriate adjustments were made for the smallness of the sample size (ref. 7). This is only necessary where there are fewer than 20 points in the distribution.

Examination of the line in figure 1 for the aged epoxy as well as the correlation coefficients in table 1 indicated that results for this aged epoxy system are not as good as for the other systems studied. Further examination of the raw data revealed that the 30-day SET yielded lower strength bonds than 0 to 4 hours or 15 days. The Wilcoxon Sum of Ranks Test was used (ref. 8) to test the statistical significance of this visual observation. The data and appropriate tabulations are shown in table 3. In this table, the B tally represents 30-day SET while the A tally corresponds to the 0 to 4 hour and 15-day SET.

Since there were more than 20 measurements in the A samples, the significance of the B Ranks total (R) was found by

$$Z = \frac{n_B\,(n_A + n_B + 1) - 2R}{\left[\dfrac{(n_A)\,(n_B)\,(n_A + n_B + 1)}{3}\right]^{1/2}}$$

where n_A and n_B are the number of measurements in the A and B tally. For the present case

$$Z = \frac{15\ (29+15+1) - 2\ (145.5)}{\left[\frac{(29)\ (15)\ (29+15+1)}{3}\right]^{1/2}}$$

$$Z = 4.75$$

The exact values of Z corresponding to important probability levels are (ref. 8)

P = 10%	P = 5%	P = 1%	P = 0.2%
Z = 1.64	Z = 1.96	Z = 2.58	Z = 3.09

Since Z = 4.75, P is below 0.2%. This means that the observed difference between the 30-day SET and the other SET times could be expected as a result of chance less than once in 500 times. Since this possibility is remote, the difference can be considered quite significant. For the aged epoxy bonds, the 30-day SET leads to significantly weaker adhesive bonds.

Perhaps the most troublesome aspect of this work involves the question of the effect of moisture on bonded polycarbonate. Essentially equivalent results were obtained by pre-conditioning polycarbonate at 60°C (140°F) (dry) or at 49°C (120°F) and 95% RH (wet) (fig. 1, ref. 5). However, after the pre-conditioning step, the polycarbonate was prepared for bonding under ambient conditions, then conditioned at 23°C (73°F) and 50% RH for the SET period. The specimens were then bonded under ambient conditions, after which half were stored 7 days at 23°C (73°F) and 50% RH before testing and half were aged 30 days at 49°C (120°F) and 95% RH. Because of these subsequent treatments, it is questionable whether the terms "wet" and "dry", as defined above, are meaningful.

The strength of one group of epoxy-bonded specimens (ref. 5) after 15 days SET was abnormally low. These specimens, both "dry" and "wet", were bonded on an unusually humid day [89% RH and 21°C (70°F)]. Another otherwise identical group were prepared at 23°C (73°F) and 50% RH. In the latter case, the strengths were markedly higher and agreed with the other SET values.

CONCLUSIONS

1. The Weibull distribution is quite useful in comparing strengths of adhesive bonds to polycarbonate.

2. Selection of adhesive is important in bonding polycarbonate.

3. Ethanol wipe and sanding surface treatments do not, apparently, affect the strength and durability of polycarbonate bonds.

4. SET times of up to 30 days do not appear to affect the strength of ambient-tested and aged specimens of Uralane 5738. However, the strength of aged specimens of Epon 828/Versamide is reduced after 30 days SET.

5. The exact effect of moisture on polycarbonate bonding cannot be determined by the results of this study.

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Table 1. Correlation coefficients for linear Weibull distribution plots

System	Correlation coefficient
Uralane	0.996
Uralane, aged	0.990
Epoxy	0.994
Epoxy, aged	0.931
Epoxy, aged-dry, ethanol wiped	0.996

Table 2. Bond strengths at $F(X) = 0.50$

System	Bond strength
Uralane	720 psi (4.96×10^6 Pa)
Uralane, aged	560 psi (3.86×10^6 Pa)
Epoxy	390 psi (2.69×10^6 Pa)
Epoxy, aged	140 psi (9.65×10^5 Pa)

Table 3. Test for significance of 30-day SET

X	Tally	Rank value	B Ranks
66	B	1	1
68	B	2	2
70	A B	3,4	3.5
72	B	5	5
76	BB	6,7	13
80	BB	8,9	17
84	B	10	10
88	A BB	11,12,13	24
92	A B	14,15	14.5
98	B	16	16
100	A B	17,18	17.5
110	AAA	19,20,21	
130	B	22	22
140	A	23	
160	AA	24,25	
170	A	26	
180	AA	27,28	
190	AAAA	29,30,31,32	
200	AAA	33,34,35	
210	AA	36,37	
220	A	38	
250	AA	39,40	
290	A	41	
300	A	42	
310	AA	43,44	

$R = 145.5$

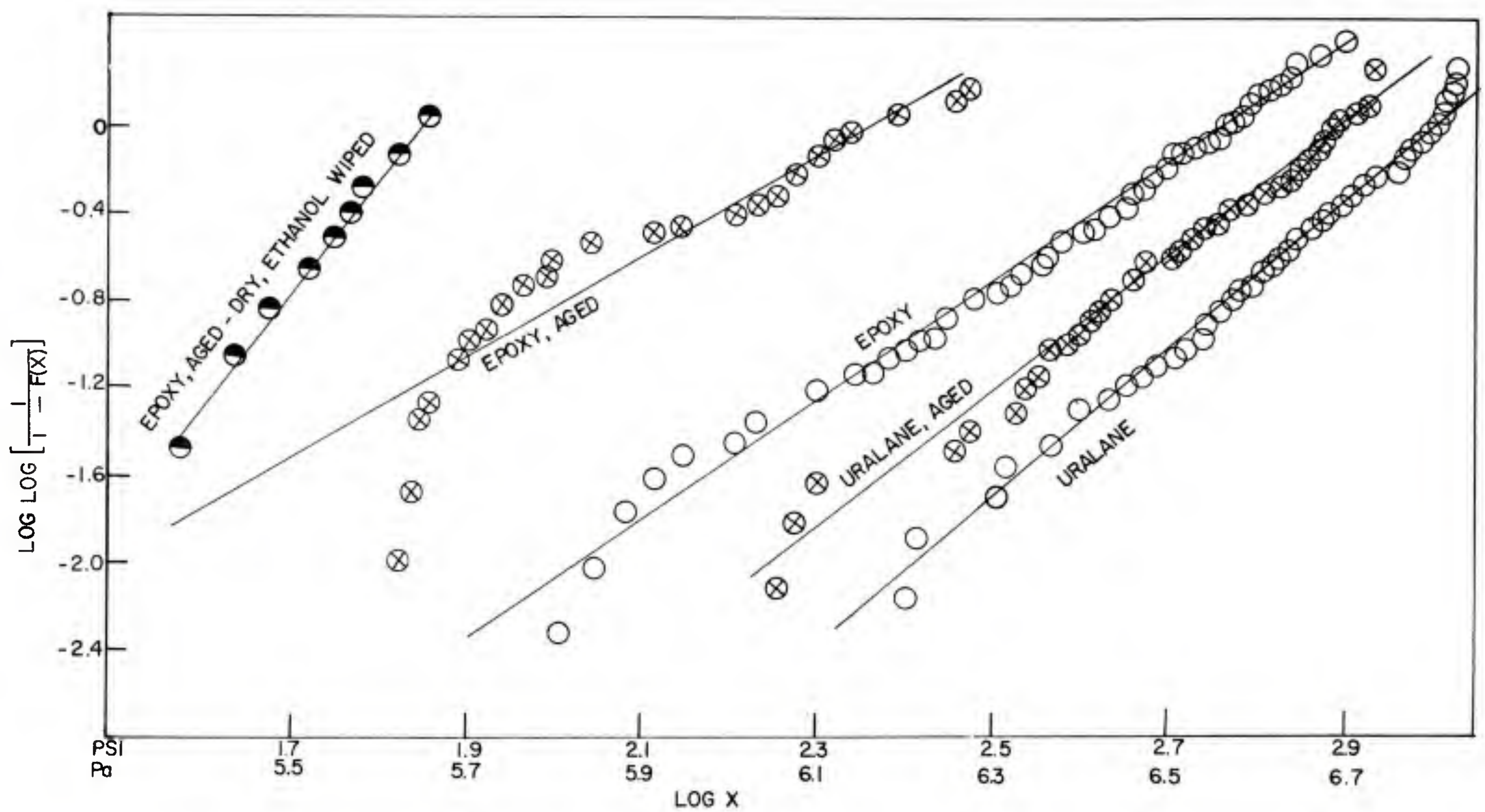

Figure 1. Comparison of adhesives and processing parameters for polycarbonate.

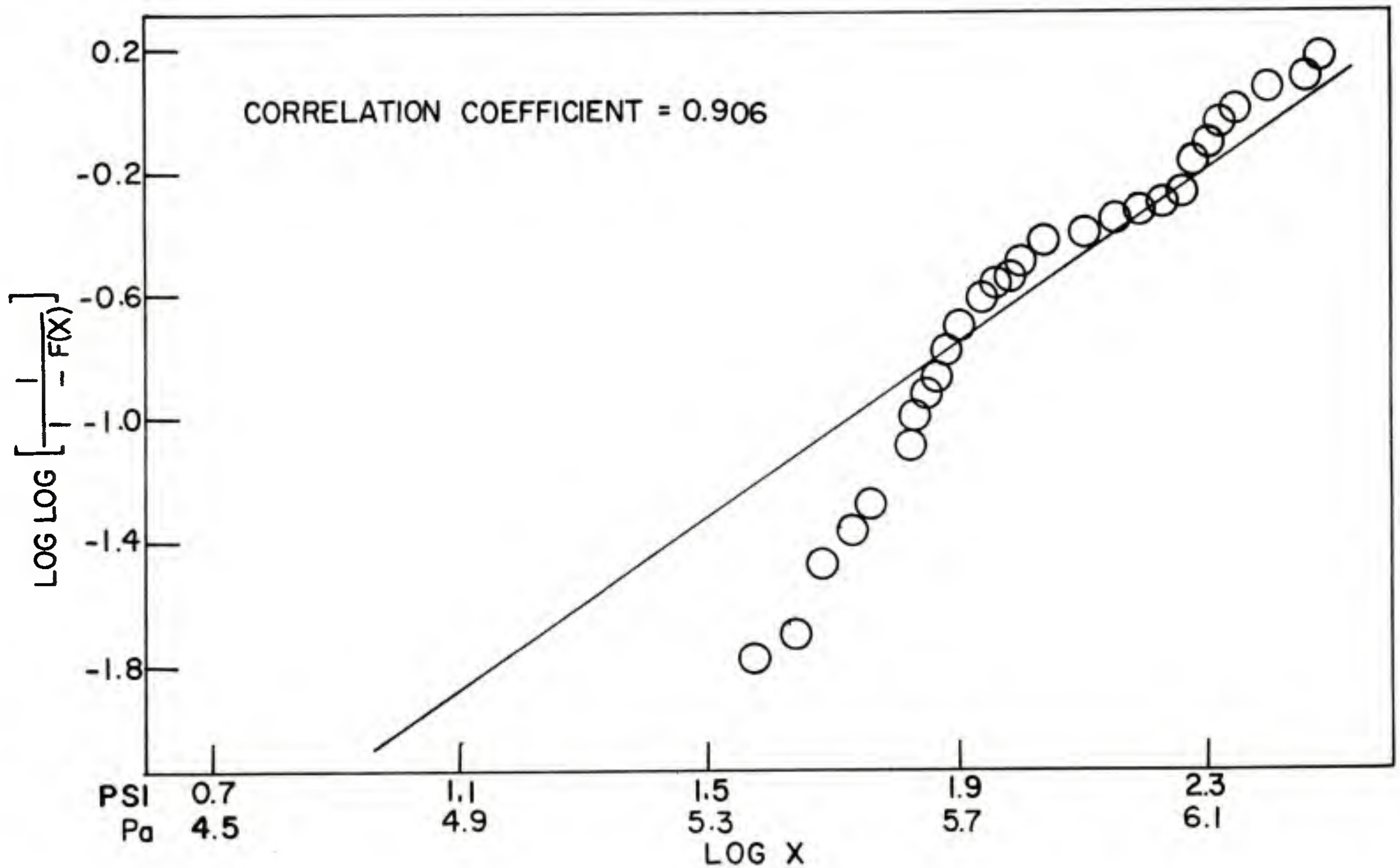

Figure 2. Weibull distribution plot for all of the strength data for aged epoxy.

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